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By

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FACTORS AFFECTING NATURAL REGENERATION OF SPRUCE IN THE INTERMOUNTAIN REGION

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INTRODUCTION

Land managers in the Intermountain Region are deeply concerned about the difficulty of obtaining natural regeneration on Engelmann spruce (Picea engelmannii Parry), subalpine fir, (Abies lasiocarpa (Hook) Nutt.) cutover areas. The spruce harvest is being drastically reduced because the cuttings fail to restock promptly, and adequately by natural means; and only limited success has been achieved through plantings. The need for more intensive management to meet future timber demands, and the increased competition of uses under the multiple use concept makes early solution of the regeneration problems urgent.

This paper reports a brief survey of the problem made in the summer of 1963 throughout the natural range of Engelmann spruce and subalpine fir in the Region. The objectives of the survey were to: (1) describe the problem more effectively, (2) provide preliminary guides for regeneration and harvest, and (3) furnish leads and direction for a sound approach in a planned study program.

Many facets of the problem will require much basic and applied research and experimentation to furnish solutions with depth and broad applicability.

During the conduct of the survey 10 National Forests were visited in the Region and 25 cutting areas were examined on these forests.

Seventeen of the areas were sampled and four of those areas were studied in detail. Personnel of the National Forests, private loggers, and foresters of various agencies were consulted, and their views of the problems, experience, and cutting results were discussed. The management of spruce is largely a National Forest problem in the Region since the spruce-fir type occurs at relatively high elevations with little of the type found on private lands at lower elevations.

LITERATURE REVIEW

There is a large volume of literature written on regeneration studies. Some of the studies which are pertinent to understanding the regeneration problems of Engelmann spruce are reviewed here. Although detailed work related specifically to natural regeneration of Engelmann spruce is limited, considerable general knowledge concerning limiting factors is available. The following factors have received attention: (1) moisture, (2) insolation, (3) seedbed requirements, (4) seed production, and (5) cutting methods.

MOISTURE

Moisture may be a limiting factor in seed germination and initial seedling survival. Roe [2/] found striking differences in germination between two soil types in an exploratory study in western Montana in 1955. Seeds were sown on two areas: one was a droughty sandy soil; the other was a black, moderately heavy loam soil which retained a high moisture content through the season. The latter germinated in excess of 9 times more seedlings (16 plots on each soil type) than the former when the same amount of seed was sown on all plots. Apparently rapid soil surface drying limited moisture for germination on the droughty sandy soil. Both locations were on the same general slope within about 10 chains of each other.

Smith (1955) reports that moisture was the most limiting factor in germination and spruce seedling survival in British Columbia. Daniels [3/] points out that spruce in Logan Canyon, Utah, germinates most readily in protected areas where large snow accumulations melt slowly in the spring. The moisture regime on these protected seedbeds is favorable in the spring when suitable temperatures for germination are reached.

First season survival of spruce seedlings is handicapped often by drought (Smith, 1955; Haig et al, 1941; Rocky Mountain Station Annual Report, 1958). Spruce seedlings do not penetrate the soil very deeply during their first growing season. Smith (1955) shows first season root penetration of about 1 1/2 inches. First-year root penetration averaged 1 1/2 inches with a range of 3/4 to 3 inches in

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2/ Unpublished data in Intermountain Forest and Range Experiment Station files.

3/ Personal discussion with Dr. Daniels.

seedlings on western Montana cutover areas. An entire seeding of Engelmann spruce in western Montana was lost to drought during the last week in August and the first week in September. Soil samples were taken surrounding the roots of dead seedlings. Moisture percent was 5 to 10 percent below the 15-percent wilting point determined for the silt loam soil. Seedling root penetration often does not keep pace with the seasonal march of soil drying.

INSOLATION

High soil surface temperatures often cause high mortality rates among first-year spruce seedings. Smith (1955) reported temperatures well in excess of the lethal temperature for spruce seedlings, particularly on burned seedbed in British Columbia. The Rocky Mountain Forest and Range Experiment Station (1958) found that shading of spruce planting stock on high elevation sites increased the survival and improved the vigor of the plants when compared with unshaded plants. First-year results were 80 percent survival for shaded plants and 32 percent in unshaded plants. In western Montana[4/] on gentle north slopes (19-29 percent) 30-50 percent losses of seedlings to heat damage was experienced on unshaded plots, as against 10-percent loss on shaded plots. Early shade protection for the newly germinated seedlings is necessary in some instances to protect them from heat damage.

4/ Op. cit. footnote 2/

Other aspects of light are also important in seedling development and survival. Ultraviolet light has been found to have harmful effects upon plants. Studies by the University of Idaho (1963) show readings in excess of 18,000 foot candles at Parma, Idaho, at an elevation of only 2200 feet. This is greater than intensities usually recorded at elevations as great as 11,000 feet. Arid intermountain air allows the passage of great quantities of light, including ultraviolet which is usually screened out by the atmosphere. They found in the Idaho studies that by screening out some of the ultraviolet light, the growth of vegetables was increased considerably. About 2 percent of the energy of solar radiation is in the ultraviolet portion of the spectrum.

Grasovsky (1929) presented a summary of data which showed the effects of different portions of the spectrum on plants as follows:

	Rays	Wave length	Effect on plants
	Ultra Violet	.042 - .400	Harmful dwarfing
visible light	Violet	.400 - .490	Phototropic
	Blue		
	Green-red	.490 - .760	CO_2 assimulation
	Infrared	.760	Temperature

Studies at the Rocky Mountain Station (1962) show that photo-syntheses of spruce seedlings is favored by partial shade. CO_2 assimilation was analyzed in seedlings grown under several degrees of shade: full, half, and no shade. The seedlings were also subjected to three light intensities: 1,500, - 3,000, - and 12,000 -foot candles. The study suggested that the optimum light intensities were somewhere between 3,000- and 12,000 - foot candles and that the optimum was probably higher in September than in June.

SEEDBED REQUIREMENTS

Seedbeds have been studied more widely than any other facet of the spruce regeneration problem. The superiority of mineral or burned seedbed, we believe, has been demonstrated quite well. Larson (1923), Griffith (1931), Parker (1952), Smith (1955), Day and Duffy (1963), Day (1964) and others consistently have shown natural forest floor, or litter to be poor seedbed. However, highly variable results have been reported on decayed wood and moss. Some writers point out that high germination may be experienced on decayed wood, but high mortality may occur later in the season when the decayed wood dries out. They all report moderate to good success on mineral and burned surfaces. Day and Duffy (1963) and Day (1964) reported best success on black muck and decayed wood in the Crowsnest Forest in southwestern Alberta. Success on decayed wood, however, was associated with moist sites. They also showed greater stocking as vegetation abundance increased up to medium abundance, but stocking was lower in heavy vegetation. The authors suggest that the medium abundance of vegetation may offer more protection and mulch for the seedlings; but that heavy abundance may inhibit seedling establishment.

SEED PRODUCTION

Production and dissemination of seed has not been widely studied in Engelmann spruce. Boe (1954) analyzed rangers' seed reports in Montana for the period, 1908 to 1953. He reported data separately for east and west of the Continental Divide. Crops were rated as good, fair, and poor. West of the Divide, five good, eight fair, and nine poor crops were reported during 22 years of record. East of the Divide, seed production was considerably lower, where only 2 good, 4 fair, and 15 poor crops were experienced during the same reporting period. Throughout the state 1926 and 1952 were both exceptionally good spruce seed years. In 1952, the spruce seed crop was bountiful throughout the northern Rockies and Intermountain areas.

In a very old cutting on the Kaniksu National Forest in northern Idaho, Roe and DeJarnette[5/] found that small seed-tree groups and 1-chain-wide strips were highly transient in nature and suffered such severe early loss to windthrow that they could not be considered a very reliable source of seed. The study showed that side seeding from the surrounding timber edge contributed seed for reproduction in a 10-chain peripheral strip around a large clear cutting.

Squillace (1954) has shown that significant spruce seed dispersal (60,000 sound seed per acre) reached out as far as 9 chains from the timber edge in a large spruce clear-cut block in western Montana. However, he points out that this occurred during a "bumper" seed year. During a poorer seed crop the quantity to reach the center of the 18-by 30-chain clear cutting would have been proportionately lower.

5/ Unpublished manuscript. Intermountain Forest and Range Exp. Station.

Windthrow becomes a serious problem in spruce seed sources left in partial cuttings or as uncut timber around and between clear cuttings. The Rocky Mountain Forest and Range Experiment Station (1959) has studied windfall in spruce cuttings in Colorado. The following summarizes their findings.

1. Twice as many windfalls per chain of cutting boundary were found on the leeward as on the windward side of clear cuttings.

2. Windfalls were as numerous in the cutting edges parallel to, as those crossing the prevailing winds.

3. Heavy windthrow was associated with cutting boundaries on ridges, saddles, or near ridge tops. Fewer windfalls were found in stream bottoms or upper, middle, and lower slopes.

4. No correlation was found between steepness of slope and amount of windfalls.

5. Cuttings in locations that funneled or concentrated wind had concentrated blowdown where the cutting boundary was exposed to increased winds.

6. Windfall showed consistent relation to the size of the opening. The amount of windfall was related to the length of the perimeter exposed.

7. Lodgepole pine was most wind resistant, with subalpine fir next, and spruce least resistant.

8. Localized pockets of heavy blowdown were found on soils of impeded internal drainage.

9. Root and butt rot was associated with windfall.

With guidelines such as above, cutting boundaries can be selected or altered to minimize the chances for windfall of the residual trees or seed source.

CUTTING METHODS

Alexander (1963) recently reported abundant reproduction on three types of cutting on the Fraser Experimental Forest. The three cutting methods were described as:

1. Clear cutting in alternate strips: Fifty percent of the area was cut over in 66-foot-wide strips.

2. Clear cutting in small groups: Fifty percent of the area was clear cut in small groups 66 feet in diameter.

3. Single tree selection: Sixty percent of the stand volume was removed.

Advance reproduction, predominantly subalpine fir (not destroyed in logging) stocked from 22-37 percent of the milacre plots. Most of the subsequent stocking came in 10-15 years after logging and raised the total stocking to 89 to 92 percent of which 60 to 59 percent of the milacres were stocked with spruce.

The growth rate of the residual stands were not stimulated by any of the cutting methods tested, neither was mortality noticeably reduced by any of the cutting methods. Windfall losses were heavy in the cutover stands.

Alternate strip cutting is recommended as the best method tested. Rate of growth in the reserve stands cannot be improved, but net increment will be increased by reducing mortality. Windfall losses can be reduced by: (1) increasing the width of cut and leave strips, and (2) eliminating improvement cutting in the leave strips.

In Alberta white spruce-aspen stands Lees (1962) recommends a two-cut system in which 60 percent of the volume of spruce is removed at about 95-years-age. Spruce seed trees are left until regeneration is established or until the stand reaches age 120 years. The final removal of the decandent aspen (at present unsaleable) amounts to a third cut. It is essential to scarify the ground at the first cut, with a medium-sized tractor equipped with a toothed bulldozer blade.

METHODS

FIELD EXAMINATION

Representative cuttings were inspected on each of the forests visited. The examinations were confined to sale areas between 3 and 10 years since logging. Because the cuttings were so recent in many locations visited, the average age since seedbed preparation was 3.3 years. The oldest was 6 years and one area had only one complete year since seedbed preparation. Cuttings older than 10 years were not sought because too much of the evidence of treatment was erased by time. Each area was scouted at the outset and an ocular estimate of stocking made. Based upon the estimated stocking, the approximate number of plots needed to give a binominal estimate within 10 percent of the mean at the 1-percent level of significance was determined. On the basis of this information, a randomly located traverse was laid out with proper plot intervals to give the required number of plots.

The following information was taken at each plot location of the four areas given intensive examination.

1. Physiographic site
2. Slope
3. Aspect
4. Elevation

5. Soil

   a. Texture

   b. Color

   c. Drainage - well drained

      - impeded drainage

   d. Stoniness - percent

   e. Depth to least permeable layer.

6. Type of seedbed

7. Estimated amount of dead shade

8. Depth of organic layer

   a. Litter

   b. Fermentation layer

   c. Humus layer

9. Moisture - estimated as wetter, dryer, or normal for the site.

10. Vegetation density

a. Grass	)	None
	)	Light
b. Forbs	)	Medium
	)	Heavy
c. Shrubs	)	

11. Residual stands

   a. Seedtrees - distance from plot - chs.

   b. Timber edge - distance from plot - chs.

12. Stocking - Dominant tree stocking plot

a. Species

(1) Subsequent

(a) Good potential

(b) Poor potential

1. $\leqslant$ 3"

(2) Advance

(a) Good potential

(b) Poor potential

1. $\leqslant$ 3"

13. Total stocking - number of trees per plot by species and size 3-inches high.

14. Conditional stocking.

Plots within crown projection of residual trees were considered conditionally stocked.

On all other areas the following minimum information was recorded.

1. Physiolgraphic site
2. Slope
3. Aspect
4. Elevation
5. Seedbed type
6. Stocking

a. Species and potential of dominant tree

b. Total number and species of seedlings

c. Conditional stocking by species

A total of 1263 plots were examined, 400 of which were intensive plots on 4 areas.

ANALYSIS OF DATA

The data were summarized by the factors considered and percent milacre plots stocked was used as the stocking statistic. Since stocking was expressed in binomial terms, nonparametric tests were used to test differences. All the stocking statistics used were highly significant by "Chi square" tests.

PROBLEM AREAS

The spruce-fir type in Region 4 seems logically to fall into three distinct areas with respect to ecology and management. For convenience these areas are designated: (1) the northern unit which includes the spruce-fir type on the Boise and Payette National Forests or roughly the portion of the region north of the Snake River and west of the Salmon River; (2) the transition unit which includes the spruce-fir type on the Wasatch, Uinta, Ashley, Cache, Bridger, and Teton National Forests; and (3) the southern unit which includes the three southern most National Forests; namely, the Dixie, Manti-LaSal, and Fishlake. (Figure 1.)

Figure 1.--Problem Areas

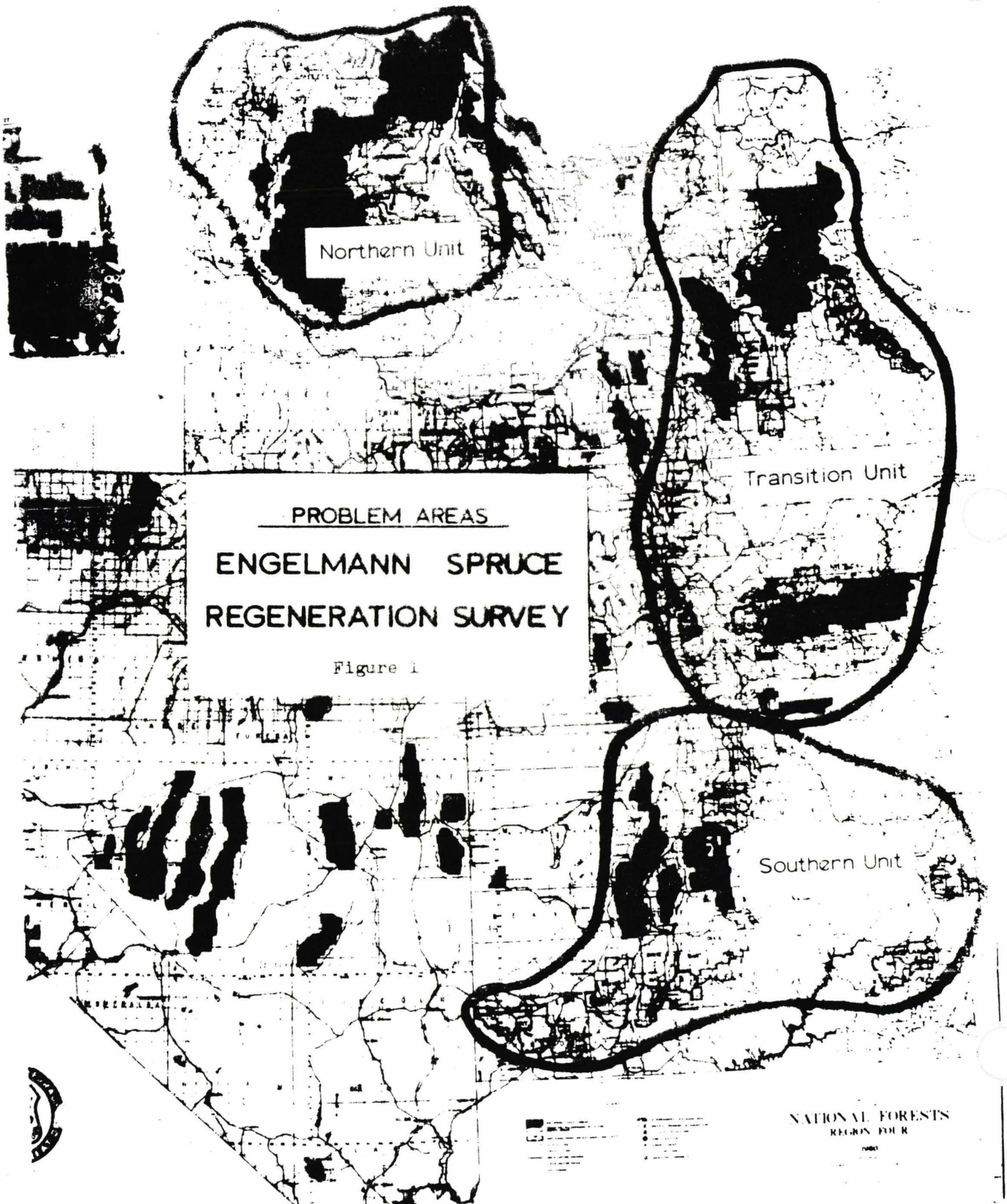
NORTHERN UNIT

The northern unit is lowest in elevation where spruce-fir stands may range from 6 to 9,000 feet above sea level. Stringers of the type may follow cool, moist creek bottoms to much lower elevations where such type extensions may enter the ponderosa pine type. The timber occurs mainly on slopes and more varied physiographic situations than the other units.

Pure spruce-fir forests are infrequent with lodgepole pine as the strongest associate species. Douglas-fir, western larch, and ponderosa pine may also be found associated with the type to a lesser degree. Aspen, if present, constitutes only a minor constituent of the stand.

The soils occupied by spruce-fir in the unit are predominantly deep, very stoney, light to medium textured loams and originate largely from granitic rock. Shallow clay layers may occur in the horizon at various depths, but often are found within 18 to 30 inches of the surface. A well-developed humus layer from $1\frac{1}{2}$ to 3 inches in depth is common under the mature forest.

The ground cover beneath the spruce-fir stands is largely dominated by Vaccinium scoparium, which very often forms a dense, pure carpet on the forest floor. In some limited areas, such as moist creek bottoms, Pachistima myrsinites may form a conspicuous part of the vegetation.


Northern Unit
Transition Unit
Southern Unit
PROBLEM AREAS
ENGELMANN SPRUCE
REGENERATION SURVEY
Figure 1
NATIONAL FORESTS
REGION FOUR

The climate appears to be favorable for the spruce-subalpine fir type. Applicable weather data is not available, but information from nearby stations may provide some insight into some characteristics of the problem area climate. A wide seasonal temperature variation is typical ranging from a low of -40° F. to a high of 100° F. The average annual temperature is approximately 40° F. There are about 90 frost-free days annually at McCall (elevation 5025) where the above information was obtained.

High intensity summer storms are common in the area Kidd (1961). Storm intensities reaching as high as 6.6 inches per hour for 5 minutes have been recorded and storms of longer duration commonly reach intensities of 3 to 4 inches per hour.

The area receives about 27 inches of annual precipitation at 5,000 feet elevation, about 16 percent of this falls in June through September. July and August each average slightly more than one-half inch per month.

Spruce sites are good and 5 to 6 log spruce trees are not uncommon. Natural regeneration appears to be much more aggressive in this unit than the other two. However, seed production seems to be less consistent here than in the southern and transition units.

TRANSITION UNIT

The spruce-fir stands in the transition unit lie at intermediately high elevations ranging from approximately 7,500 to 10,000 feet above sea level. The best spruce occurs on lower north and east slopes, but the type also occurs on south and west slopes. Some stringer types of spruce follow stream courses and wet bottoms into the Douglas-fir type, but these are of limited extent and insignificant in the total problem area. The teneral physiography in the spruce-fir type in this unit is more broken than that of the southern unit, but occasionally the mountains top out into a plateau type.

The principal tree species associated with spruce-fir in this unit is lodgepole pine and aspen. Lodgepole pine is a strong contender on the spruce-fir sites and very often overtops and suppresses the spruce and fir. Much of the spruce and fir has originated either in admixture with or as an understory in lodgepole pine and aspen stands. The spruce and fir may remain in the suppressed understory for long periods of time, but they release well when the overstory breaks down or is removed. Aspen is present in varying admixtures throughout the spruce-fir-lodgepole pine stands of the unit, but nowhere does it develop into as fine a tree as the aspen found in the southern unit. This is considered a transition unit because aspen tends to diminish in importance from south to north and lodgepole pine tends to replace it.

Soils range from very fine sandy texture to heavy loams. They are deep, very stoney, and are derived from sandstones, quartsites, or granitic rocks. Some of these soils tend to be droughty and may dry out too rapidly in the spring for optimum germination. They are inclined to be highly erosive, although they are more stable than single grain, coarse granitic soils. Bare soil surfaces are subject to sheet and rill erosion as evidenced by the abundance of large rocks floating in or near the surface. Without protection the bared soil surfaces provide a very unstable seedbed.

The most prominent ground vegetation in the spruce-fir stands from the Ashley Forest on the south end to the Teton in the north, and extending north from there to Yellowstone Park is grouseberry Vaccinium scoparium, and elk sedges, Carex sp., Pachistima myrsinites has been observed weekly represented on the Ashley and Uinta Forests but it comprised a very substantial part of a well developed plant community in the South Murphy Creek sale area in the Hoback River of the Teton Forest.

The mountain masses of the unit rise abruptly from the floor of the dry plains and although considerable annual precipitation may occur in the mountains the environment is undoubtedly influenced by the hot dry summer air from the valleys and deserts below. Much of the spruce-fir type is found well back from the Wasatch front. The Davis County watershed with an annual precipitation of about 45 inches has relatively little tree growth. The great amount of precipitation apparently is not effective because of the high evaporation rate. Therefore, favorable habitat for tree growth is found farther back from the front. The climate in the spruce, fir stands can be characterized best as a short growing season (about 80 frost-free days at Island Park, Idaho, elevation 6,300 feet) with frequent occurrence of high intensity summer rains. These summer storms have shown intensities as high as 8 inches per hour and they create problems of soil movement (Croft, Marston (1950.)) Mean annual temperature at 6,300 feet is 38° F. Total annual precipitation exceeds 30 inches with one-quarter of it occuring from June through September.

SOUTHERN UNIT

The southern unit is the highest of the problem areas and the spruce-fir stands range from about 9,000 to 11,000 feet in elevation. Much although not all of the spruce-fir type occurs on high mountain plateaus or on gentle slopes in ravines or coves in the plateau.

Spruce is usually the predominant species in the spruce-fir stands of this unit but in some instances aspen may constitute a large proportion of the stand. Aspen develops into a fine tree here reaching diameters about 20 inches and several logs high. Douglas-fir occurs in some of these stands, but only as a very minor constituent. The timber stands are interspersed with large open grassland parks.

Past animal use, particularly by sheep, and heavy current use by a large deer population have resulted in extremely sparse ground vegetation. The range surveyors find an average of about 50 percent cover in the meadows and parks. Within the uncut stands as well as on cutover lands the very low density of ground vegetation and the limited accumulation of litter and humus contributed little to the protection of the soil. As a result, an erosion pavement is widespread throughout these stands.

The soils are very stoney and range from moderate textured loamy to heavy textured clay loam soils with clay bands or layers at 20 to 36 inches. These soils were derived largely from lava or basaltic rocks.

Considerable basic weather data describing the climate in this area has been reported by Ellison (1954). It is based upon records obtained from an alpine climatic station located at 10,000 feet elevation.

Nine-year records show that maximum temperatures rarely exceed 75° F. and the average length of the frost-free period is about 80 days. Great differences in temperature between south-facing and north-facing slopes are observed but instrumented studies of this feature are lacking.

In Ephraim Canyon at 10,000 feet elevation in the subalpine zone there is very little soil freezing in winter except where slopes or ridges are swept bare of snow by the winds. Frost heaving occurs mainly in the autumn before the ground is snow covered and in the spring after snowmelt. Heaving affected only 2 to 3 c.m., about 1 inch, of the soil under bared surfaces.

Thirty-five year records show a mean annual precipitation of 30 inches and two-thirds of it falls from November through April as snow. The months of July, August, and September average about one and one-half inches each. However, precipitation during these months may vary from a low of .24 to a high of 6.14 inches.

In this problem area high intensity summer storms are likely to occur during the months of July through October. In a sample of 79 storms studied; 36 occurred in July, 26 in August, 15 in September, and 2 in October. Summer rainfall intensity of 2.76 inches/hour for five minutes have been recorded.

Soil moisture is usually adequate in the subalpine zone. Ellison has shown that soil moisture declines progressively through the season from 40 percent in the spring to 15 percent in the fall. In only 1 out of 16 years soil moisture dropped below the wilting coefficient. During 6 out of 16 years uniform summer precipitation kept the soil moisture of the upper 6 inches of soil above the wilting coefficient all summer.

Evaporation is rapid most of the time at these high elevations.

HISTORY OF CUTTINGS

Some of the early cuttings in the Region date back 30 years or more, but only recently has extensive cutting in the spruce type extended throughout the Region. The increased activity in the resource has been brought about to some degree by demands of industry for timber, but even to a greater extent by salvage cuttings in stands attacked by the Engelmann spruce beetle. Most of the cuttings prior to about 1957-58 were partial cuts with no attempt at seedbed preparation other than that obtained incidentally to logging activity. The year 1958 and later years has seen a shift to practically all strip or block clear cuts and a thorough job of seedbed preparation and slash disposal. Cuttings in strips and windrowing and burning slash along the center line of the strips has become a common practice. This practice has resulted in a 100 percent slash disposal and very barren seedbeds nearly completely exposed and devoid of residual material on many cutting areas. Many of the strips are oriented roughly with the long axis at right angles to the prevailing winds. Very often the strips are situated with the long axis in a north-south direction exposing the entire strip to the noon sun.

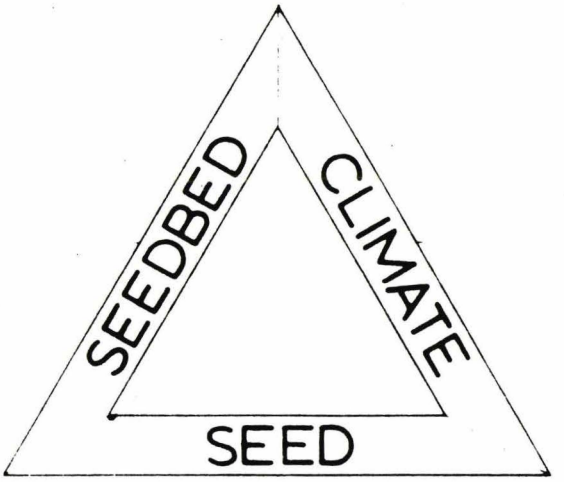
Most of the cuttings range in size from less that 10 acres to as high as 1000 to 1500 acres. Very often the size of the cutting is limited to the area infested by beetles.

RESULTS

A supply of viable seed, a receptive seedbed, and climate compatible with germination and seedling requirements comprise the basic prerequisites for successful natural regeneration. If one of the legs of the triangle is missing regeneration fails. Before we are accused of oversimplification we hasten to add that many factors within these broad categories may benefit or restrict germination and seedling survival. (Figure 2)

Figure 2.--Factors influencing seedling establishment

THE NATURAL REGENERATION TRIANGLE



TYPE
MICRO-HABITAT
SHADE
ORGANIC MATTER
VEGETATION
SOIL
DISEASE
GRAZING & BROWSING
EROSION

SOURCE
SEED TREES
TIMBER EDGE
SPECIES
QUALITY
VIABILITY
INSECTS
DAMAGE
RODENTS

INSOLATION
LIGHT INTENSITY
HEAT
MOISTURE
SNOW PATTERN
SUMMER STORMS
FROST
HEAVING
SOIL DETACHMENT

PHYSIOGRAPHIC SITE

ELEVATION
EXPOSURE
SLOPE

Figure 2.--Factors influencing seedling establishment

The problem of attaining spruce regeneration is not uniformly critical throughout the Intermountain Region. Parts of the Region, specifically the northern tier of forests show a high potential for successful stand regeneration. Other parts of the Region, such as the southern unit in Utah are most critical and in all probability will require special practices to achieve success. Although, local physiographic site was too limited to show any differences, nevertheless, when physiography is considered in its broadest sense, i.e., the entire region, it is quite significant.

PHYSIOGRAPHIC SITE

The most obvious, and most significant element of physiographic site is the remarkable change in elevation where the spruce stands grow. Stands in the study ranged from a low elevation of 6500 feet on the Payette Forest in the northern unit to a high of nearly 11,000 feet in the southern unit. This represents a change of 4500 feet in elevation in an areal distance of about 530 miles from north to south or a range of about nine degrees latitude.

Stocking of subsequent seedlings of all species shows a high degree of correlation with elevation (figure 3). As one progresses north and drops in elevation, regeneration increases and the sites tend to be less severe. The effect of years since seedbed treatment and the proportion of receptive seedbeds were tested and found to be nonsignificant in relation to stocking.

Figure 3.--The Relation of Subsequent Stocking all Species to Elevation

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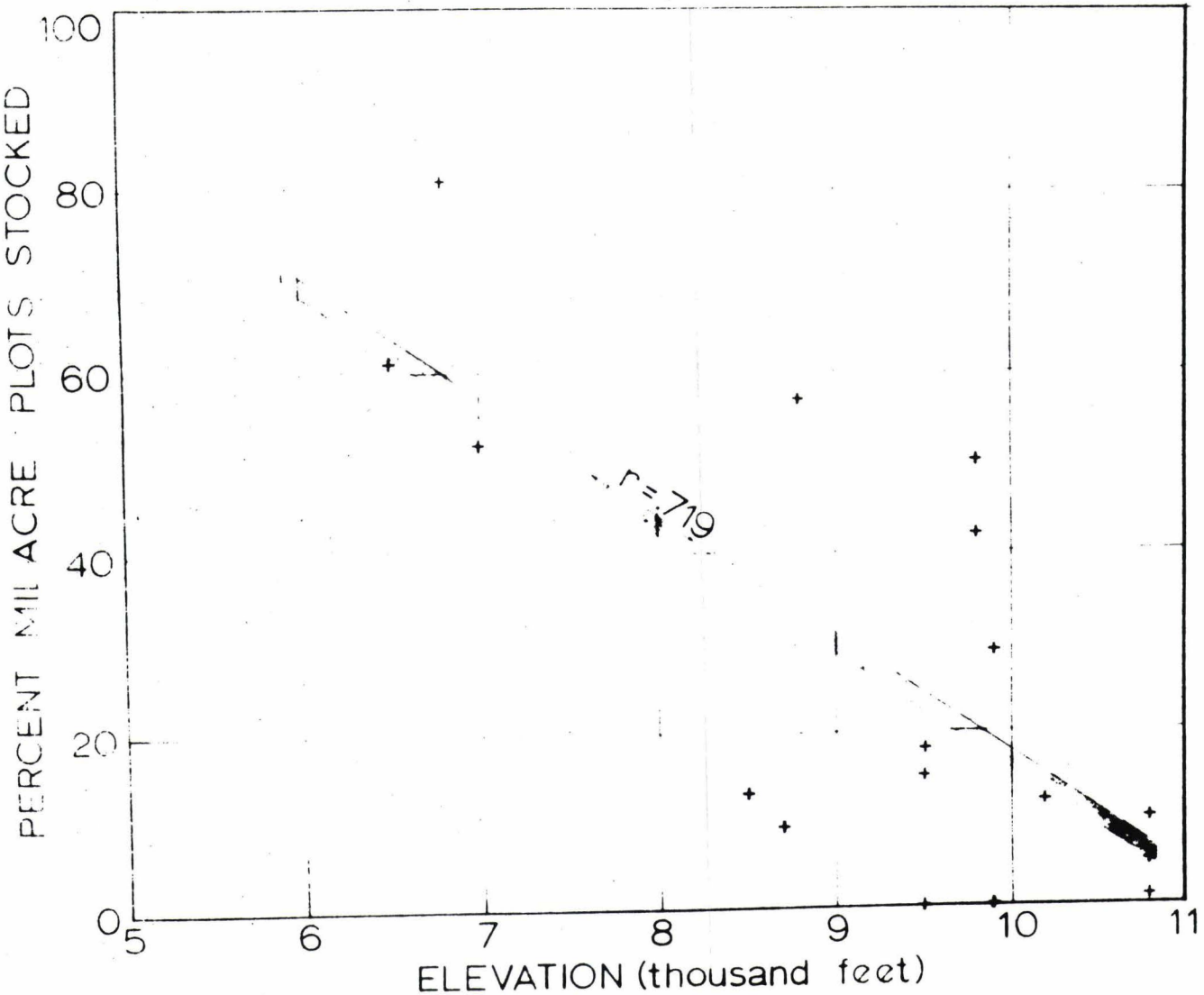
THE RELATION OF SUBSEQUENT STOCKING ALL SPECIES TO ELEVATION



The range of exposure and slope encountered on the cuttings examined was not large enough to provide significant data. The majority of the cuttings were on plateaus and lower north slopes. Special studies will be required to isolate the effect of physiographic site more specifically.

The general physiography and particularly elevation, exerts an overall influence on the regeneration situation. This effect comes largely through modification of climatic factors. Some of the effect of the general physiography is evident within the consideration of individual factors affecting regeneration.

SEED

A supply of seed disseminated in adequate quantities in a vital leg of the regeneration triangle. Without it the most favorable seedbed and climate are of no avail. There are several ways of supplying seed such as leaving scattered seed trees or shelterwood left in partial cuttings or uncut timber left around the margin of clear-cut blocks, strips, or patches. An exception to this is lodgepole pine, particularly, when a large proportion of the trees have serotinous cones attached to the slash. In this instance the seed is released from the scattered slash when it lies close to the ground. Aspen propagates primarily as root sprouts and so does not depend upon seed dissemination. Aspen seed is disseminated in the spring or early summer and has such transient viability, two weeks or less, that unless it falls upon a wet seedbed and germinates within a few days it is lost. For this reason aspen seedlings are extremely rare. Engelmann spruce and subalpine fir, however, both depend solely upon seed for regeneration and the seed is disseminated from standing trees only with the aid of gravity and wind. Spruce seed particularly is light and disperses long distances. Regardless of how far spruce seed may be disseminated from seed trees, seedling establishment is dependent upon the quantity of seed that falls in suitable microhabitats.

The establishment of seedlings in relation to seed trees is more meaningful than seed dispersal alone, (figure 4). These data taken on 400 plots show that seedling establishment as well as seed dispersal is strongly related to the distance from the seed source. For example, figure 4 shows a stepwise reduction in spruce stocking as the distance from the timber edge increases. As the volume of seed dispersed from the seed source diminishes at greater distances from the timber edge, the probability of seed falling in a suitable microenvironment decreases. The other species comprised mainly of subalpine fir and lodgepole pine do not show the same relationship. Lodgepole pine seedling establishment is not tied into the timber edge because of the different dispersal habit (cones attached to slash). Subalpine fir also shows considerably greater amplitude with respect to microenvironment, hence, it does not fit the same pattern as Engelmann spruce.

Figure 4.--The Relation of Stocking to Distance from Seed Source

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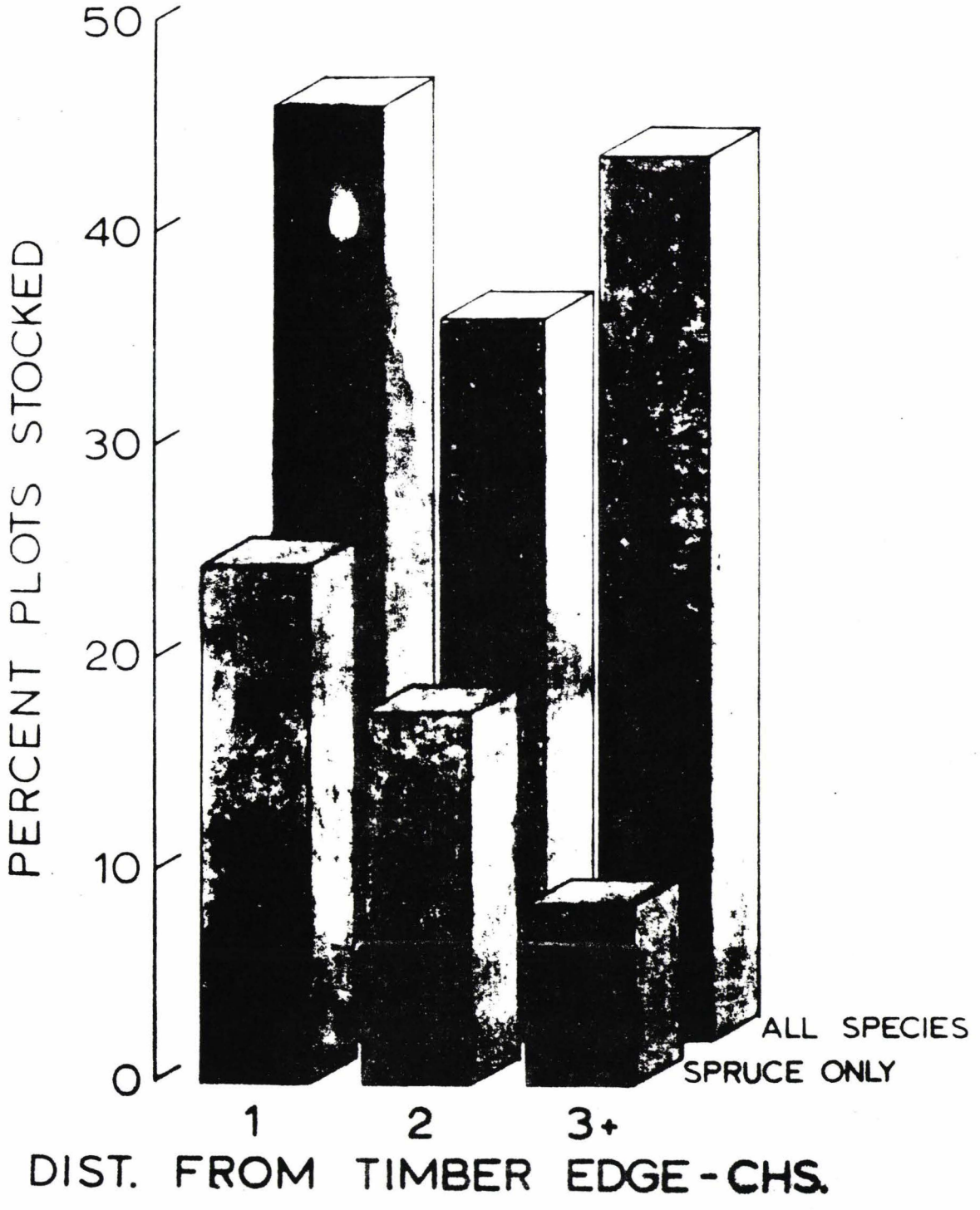
THE RELATION OF STOCKING TO DISTANCE FROM SEED SOURCE



Figures 5 and 6 show the same kind of data but it is based upon 100 plots taken upon a single type of seedbed. These data were gathered on an area burned over in a natural fire in September 1958 on the Payette Forest. The fire burned the area so uniformly that 93 percent of the seedbed was burned hard enough to remove most of the humus layer and expose mineral soil. During the past five seasons, a moderate to heavy cover of vegetation, comprised chiefly of elk sedge, (Carex sp.) fireweed (Epilobium augustifolium), beargrass, (Xerophyllum tenax), grouseberry, (Vaccinium scoparium), and several species of grass has developed. Although the vegetative cover was quite uniform on the area, much mineral soil was still visible between the plants. The south and west side of the area studied was bordered by a full stand of mature and overmature spruce, subalpine fir, and lodgepole pine. The spruce made up more than half the number of dominant trees in the stand and were generally full-crowned, relatively vigorous trees and furnished a good seed source along one side of the area. The study extended out into the burn in excess of six chains and no spruce was found beyond.

Figure 5.--The Relation of Stocking to Distance from Seed Source

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Figure 6.--The Relation of Stocking to Distance from Seed Source

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Figure 5.

THE RELATION OF STOCKING TO DISTANCE FROM SEED SOURCE

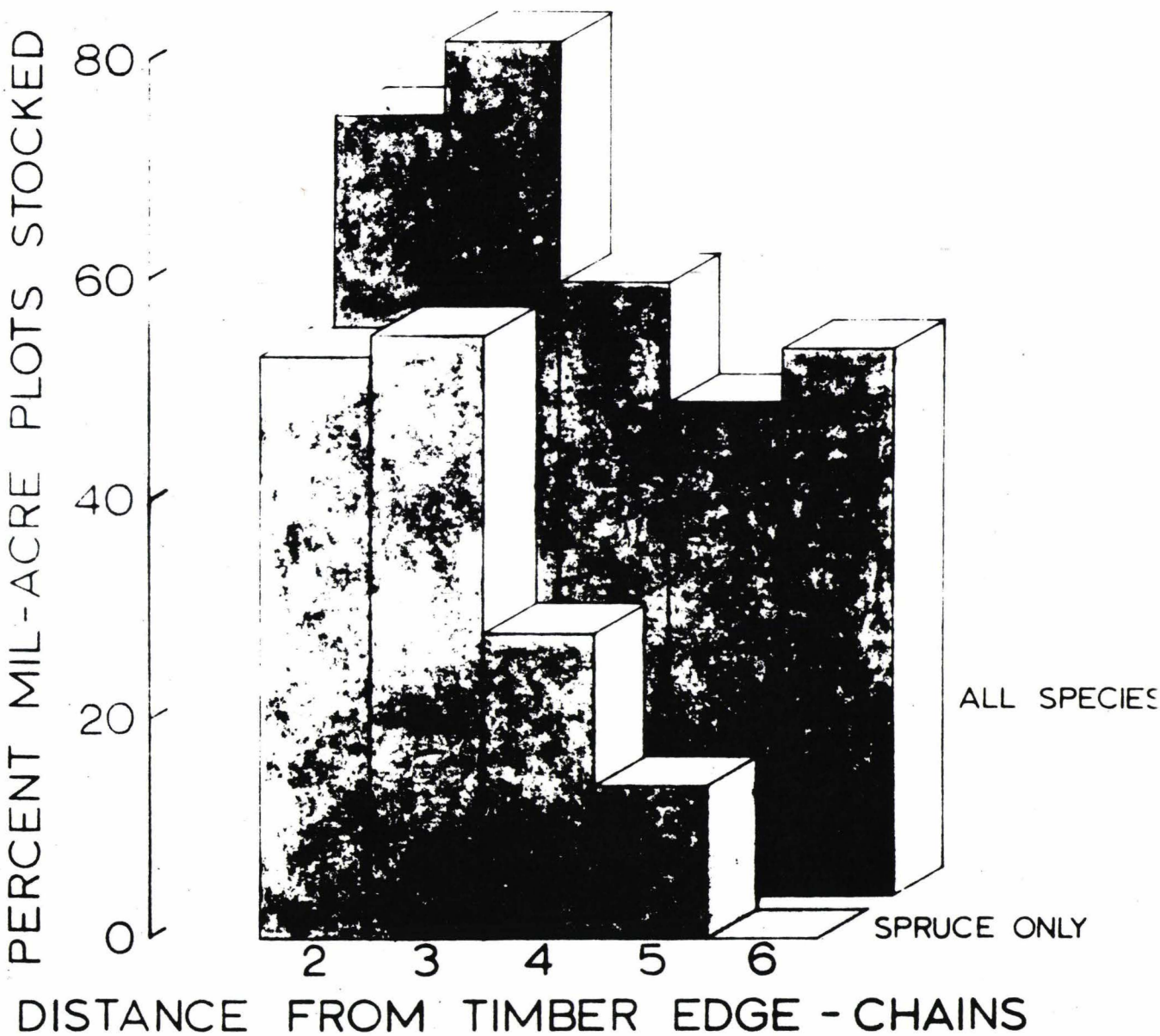
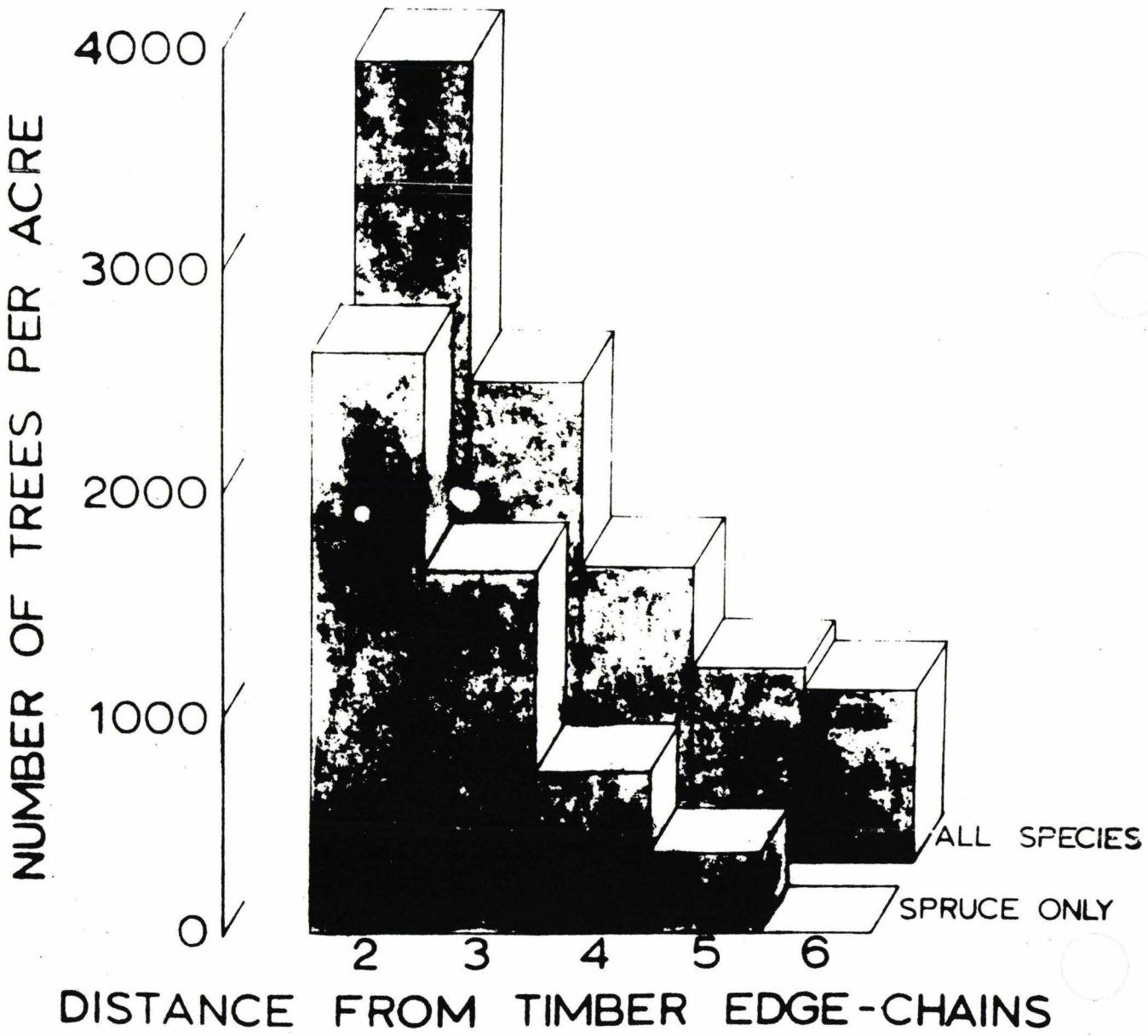


Figure 6.

THE RELATION OF STOCKING TO DISTANCE FROM SEED SOURCE



The establishment of spruce seedlings was limited to within about five chains of the timber edge. Figure 5 reveals some interesting relationships in that a larger percent (50 percent and more) of the milacres were stocked with spruce up to about 3.5 chains from the edge but beyond that point lodgepole pine and subalpine fir stocked the majority of the plots.

When these same data are summarized on the basis of total number of trees per acre as shown in figure 6 rather than stocked plots the trend becomes more emphatic. This shows that spruce dominates the reproduction in numbers and also that the other species follow the same trend due mainly to the subalpine fir. When the lodgepole pine stocking which comprises only 6 percent of the total is arrayed over distance no significant trend is discernible.

QUALITY

Daniels[6/] has 20-year seed production records on individual spruce and subalpine fir trees in Logan Canyon. His records show that spruce in that location is a very frequent seeder, and that on a given plot some seed is produced every year, not necessarily on the same trees. He found viability to be around 80 percent.

6/ Unpublished records at Utah State University, Forestry School.

Curtis (1958) determined germinative capacity for Engelmann spruce samples from the Boise, Bridger, Dixie, Fishlake, Manti-LaSal, Payette, Targhee, and Uinta Forests to range between 50 and 70 percent. He also reported that some of the 1955 seed from the Fisklake and Dixie National Forests had been infested with unidentified insects which lowered the viability values slightly.

Forest personnel on the Manti-LaSal reported that a collection of 5 bushels of spruce cones collected in 1962 yielded seed which was found by cutting tests to be hollow. Personnel on the Dixie Forest also pointed out seed insect problems.

DAMAGE

Although we were unable to obtain direct evidence of rodent damage to seed, several areas, particularly the Mill Hollow Sale area on the Uinta Forest showed a great amount of surface disturbance which indicated unusual amounts of rodent activity. This was enough to arouse the suspicion that rodents might have played a role in reducing stocking. Seed traps maintained on the Mill Hollow area by the Ranger showed a substantial dissemination of seed on the area, and also some seedlings were started which disappeared later.

SEEDBED

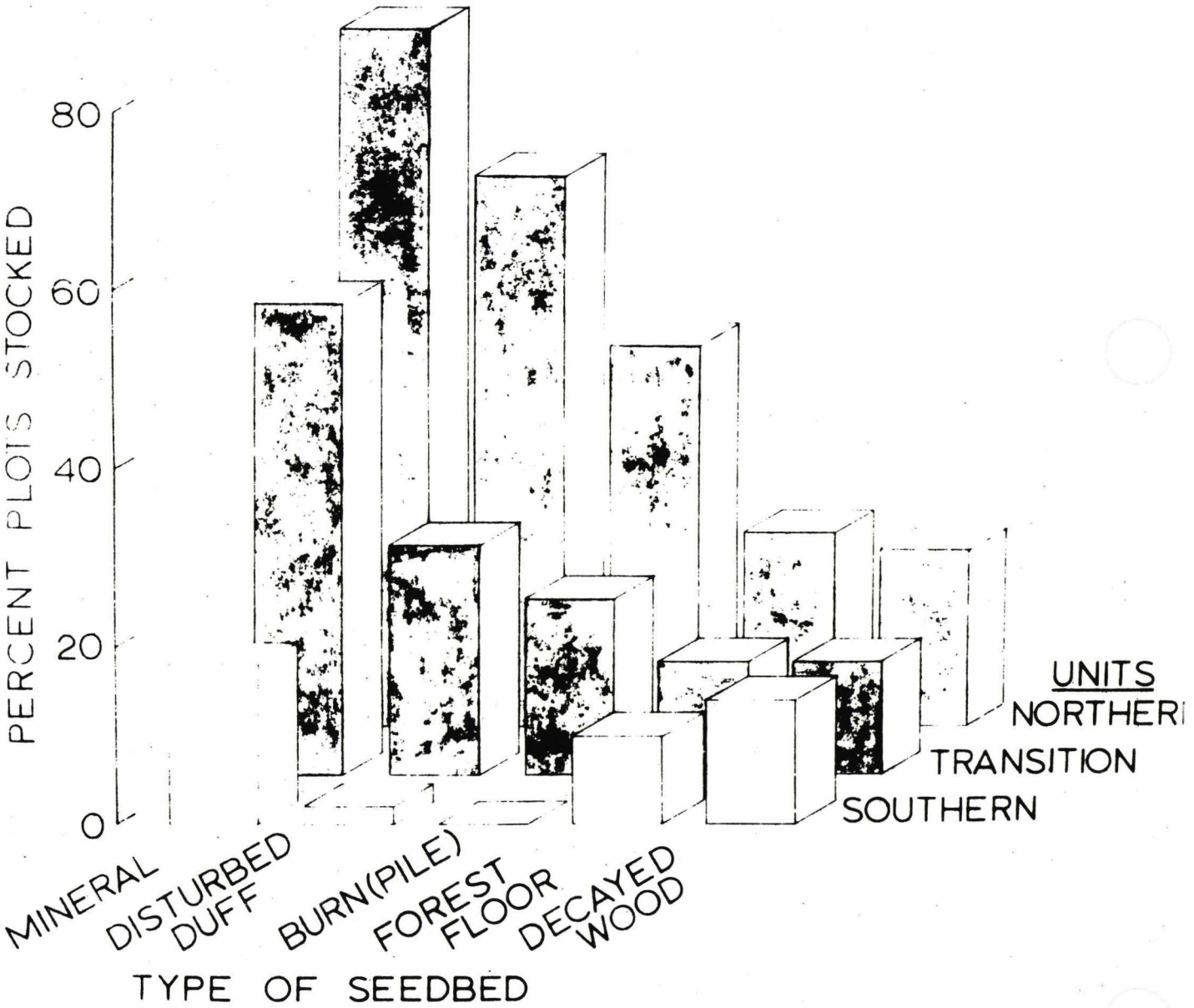
Type

This survey shows that mechanically exposed mineral soil was superior to all other types of seedbed in all three problem areas. The existing relationship is shown graphically in figure 7 based upon 1263 plots. It shows rather dramatically the decreasing probability of successful stocking from the northern to the southern problem area. Decayed wood and natural forest floor were the poorest seedbeds except in the southern unit. Here we found no stocking whatsoever on the burned piles or windrows and disturbed duff made a very poor showing. The burned seedbed was comprised of loose ash layers several inches deep, and the concentration of fuel had caused such high heat that large rocks were fractured. Observations on the Coram Experimental Forest in Montana have shown that such heavily burned spots may take five years or longer before they are reinvaded by vegetation, including spruce and larch seedlings.

Figure 7.--Stocking related to seedbed type and problem area.

Figure 7.

STOCKING RELATED TO SEEDBED TYPE AND PROBLEM AREA



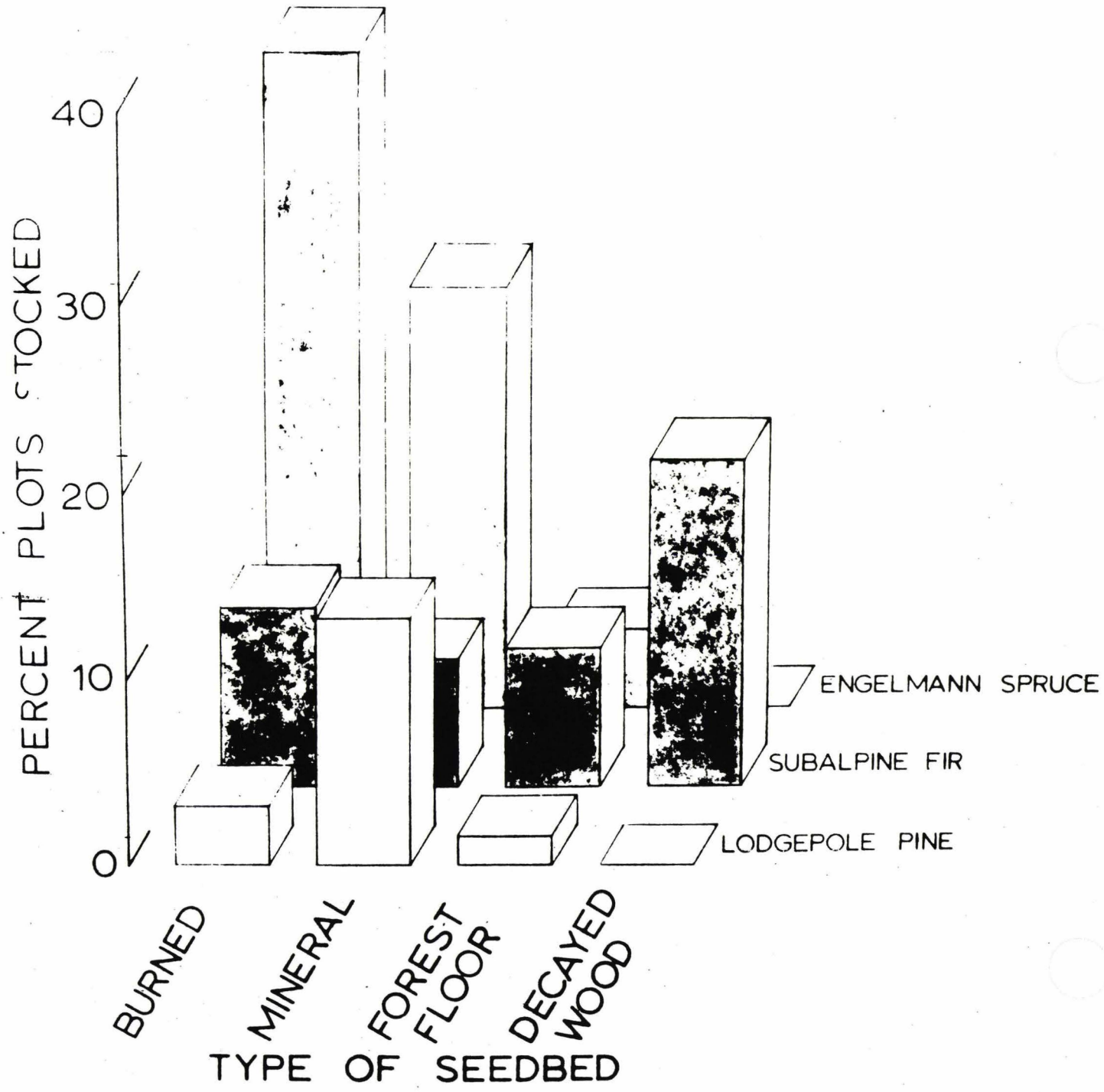
The effectiveness of seedbed type is, of course, influenced by factors such as shade, other vegetation, moisture, soil type, animals and others. In the southern unit most of the samples on decayed wood and natural forest floor were shaded. This might possibly have caused them to show up better. On the other hand, the mineral soil, disturbed duff, and burned piles were all unshaded and largely devegetated. The exposure of these seedbeds was severe. Furthermore, the reproduction represented in the figure includes all species of subsequent reproduction.

Species react differently to the types of seedbed. Figure 8, based upon 1263 plots, shows relative stocking by four types of seedbed and three species for all problem areas combined. It is interesting to note that for spruce alone burned seedbed is superior, followed closely by mineral soil. Natural forest floor and decayed wood are very poor. Subalpine fir, on the other hand, makes its best showing on decayed wood. This points up two things. First, that the composition of the regeneration stand is drastically changed by the different seedbed types and second, that subalpine fir exceeds both spruce and lodgepole pine on the natural or intact type of seedbed which would indicate that subalpine fir might be the lone climax species in a forest untouched by fire or other disturbance.

Figure 8.-- Stocking related to species and seedbed type.

Figure 8.

STOCKING RELATED TO SPECIES AND SEEDBED TYPE



Aspen was not included in the species breakdown for two reasons. (1) Since it propagates largely by root shoots, it is not tied so closely to seedbed condition and (2) in the southern and lower transition unit where aspen is important the animal damage was so heavy as to very nearly exterminate it. Consequently the sample obtained is so small as to be practically meaningless.

Microhabitat

The microenvironment is the crux of spruce seedling establishment and survival during the early critical years in the life of the seedlings. Any survey of spruce regeneration must look closely at these factors. Many of them are difficult to measure and methods used in this survey were crude but they do serve to point to some leads and areas in need of further attention. Microhabitat as used in this discussion consists primarily of elements of the seedbed that might modify the general situation.

Shade

Any factor which modifies the general seedbed enough to cast some shade, whether it be topographic shade or a direct shield to the sun's rays created an important microhabitat for seedling survival. Dead shade on the milacre plot was estimated as the percent of the seedbed surface that was shaded by humps, edges of depressions, sticks, logs, stones, and any other nonliving material. The estimate was made independently of shade cast by living vegetation such as grass, shrubs, forbs, or trees.

All species were favored by large amounts of ground shade. This was quite obvious to the observer on the ground; therefore, it is not surprising that the data (figure 9) show a reasonably emphatic increase in stocking as the percent of shade increases. Some of the stocking shown in the sero shade category may be misleading since vegetation also cast shade which was beneficial to the seedlings despite the fact that no dead shade was recorded. However, because of the relative importance of the dead shade, the trend was not masked by other factors. The observers gained the impression during the survey that shade was the overriding factor involved in seedling survival and we feared that our rough estimate of shade might not generate meaningful statistics. However, we were agreeably surprised at the result and the outcome lends considerable credence to our impressions gained in the field.

Figure 9.--The affect of dead shade on seedling establishment

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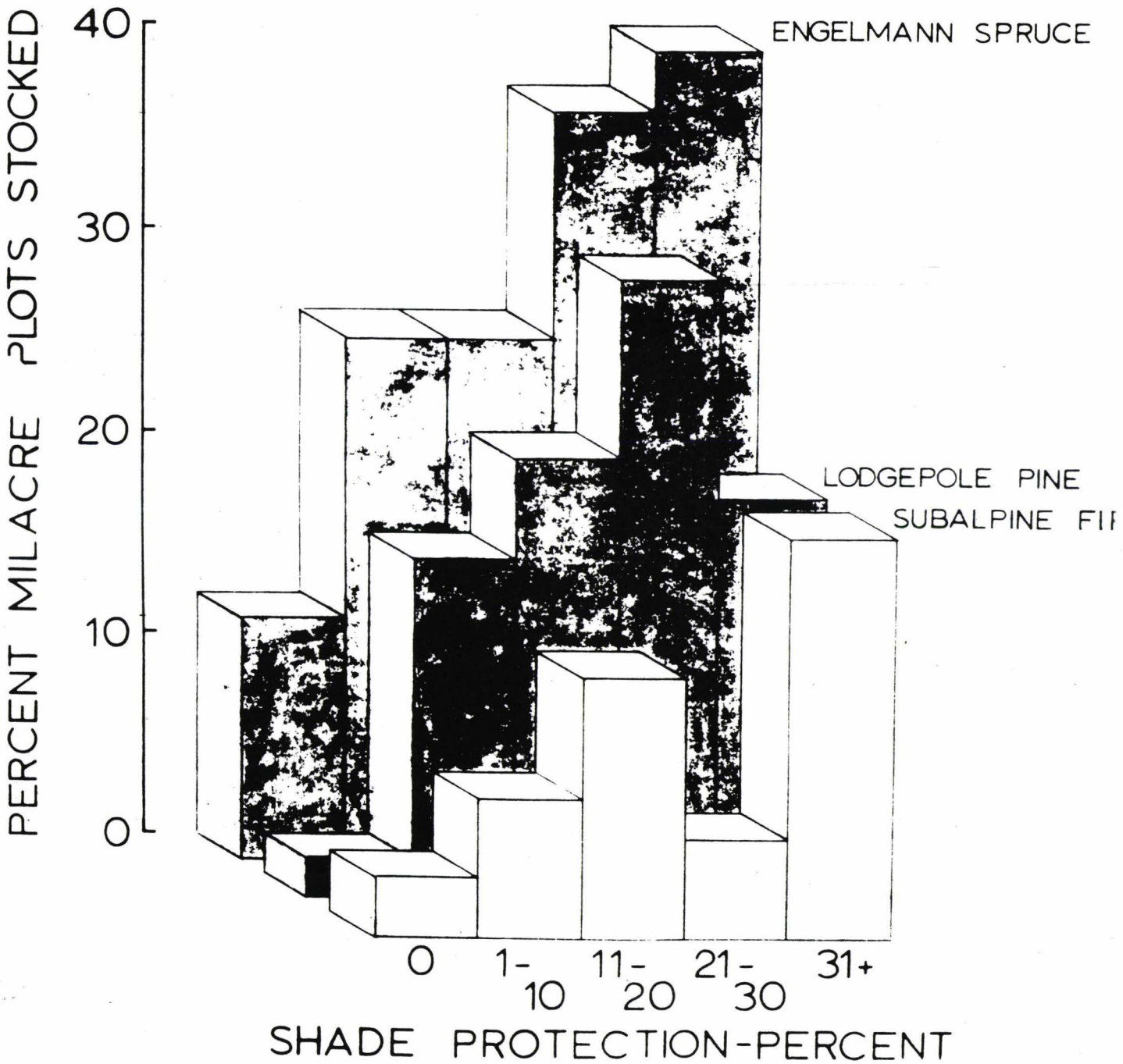
Figure 9

THE EFFECT OF DEAD SHADE ON SEEDLING ESTABLISHMENT



Organic Matter Depth

The depth of organic matter on the seedbed whether it be a well organized L F and H layer or an accumulation of litter or other debris, constitutes an inhibiting layer for the establishment of seedlings by some species. Thus, on areas where the depth of organic matter exceeded two inches, spruce and lodgepole pine were eliminated, (figure 10). For spruce this can be explained upon the fact that first-year root penetration is very feeble. In British Columbia, Smith (1955) found it to be about 1-1/2 inches and in western Montana Roe[7/] found that the range of first-year root

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7/ Op. cit. footnote 4/

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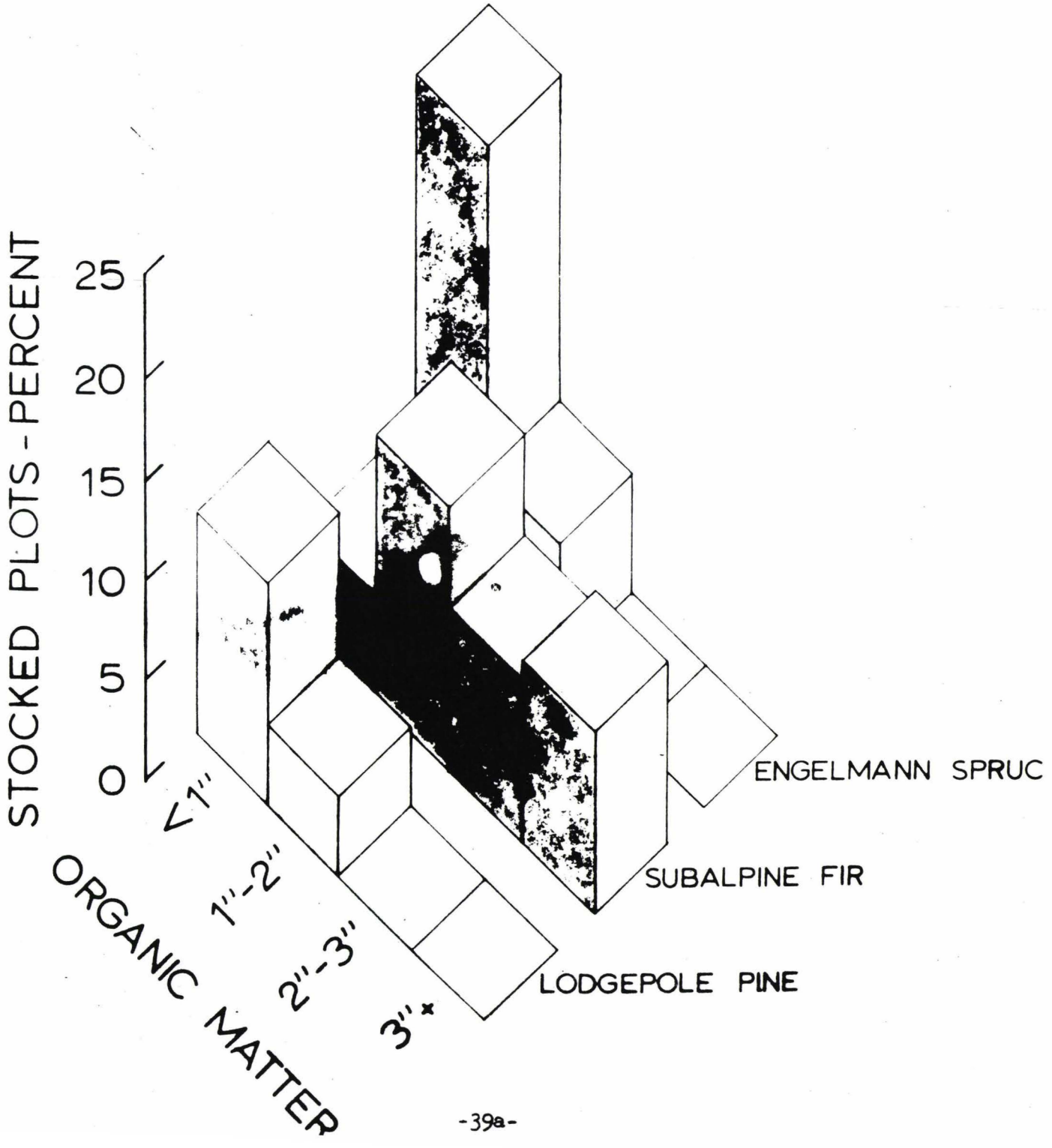
penetration ran from .75 inch to 3 inches with an average of 1-1/2 inches. Spruce seedlings that penetrate only 1-1/2 inches into the duff are lost whenever the duff dries out during the first season. It is a common sight in spruce stands to observe countless seedlings in the spring on duff layers only to find them gone by autumn.

Figure 10.--The relation of stocking to organic matter depth.

Figure 10.

THE RELATION OF STOCKING TO ORGANIC MATTER DEPTH



Subalpine fir is not hampered especially by greater depths of organic matter. Here again is evidence to explain why subalpine fir comprises the predominant species in advance reproduction started and developed under overwood. Smith (1955) and Day (1964) point out this relationship also. In completely undisturbed stands protected from fire and other disturbing factors subalpine fir might completely dominate the stand to the elimination of Engelmann spruce and other species such as lodgepole pine. Here again the evidence is pointing to subalpine fir as a candidate for the final climax type.

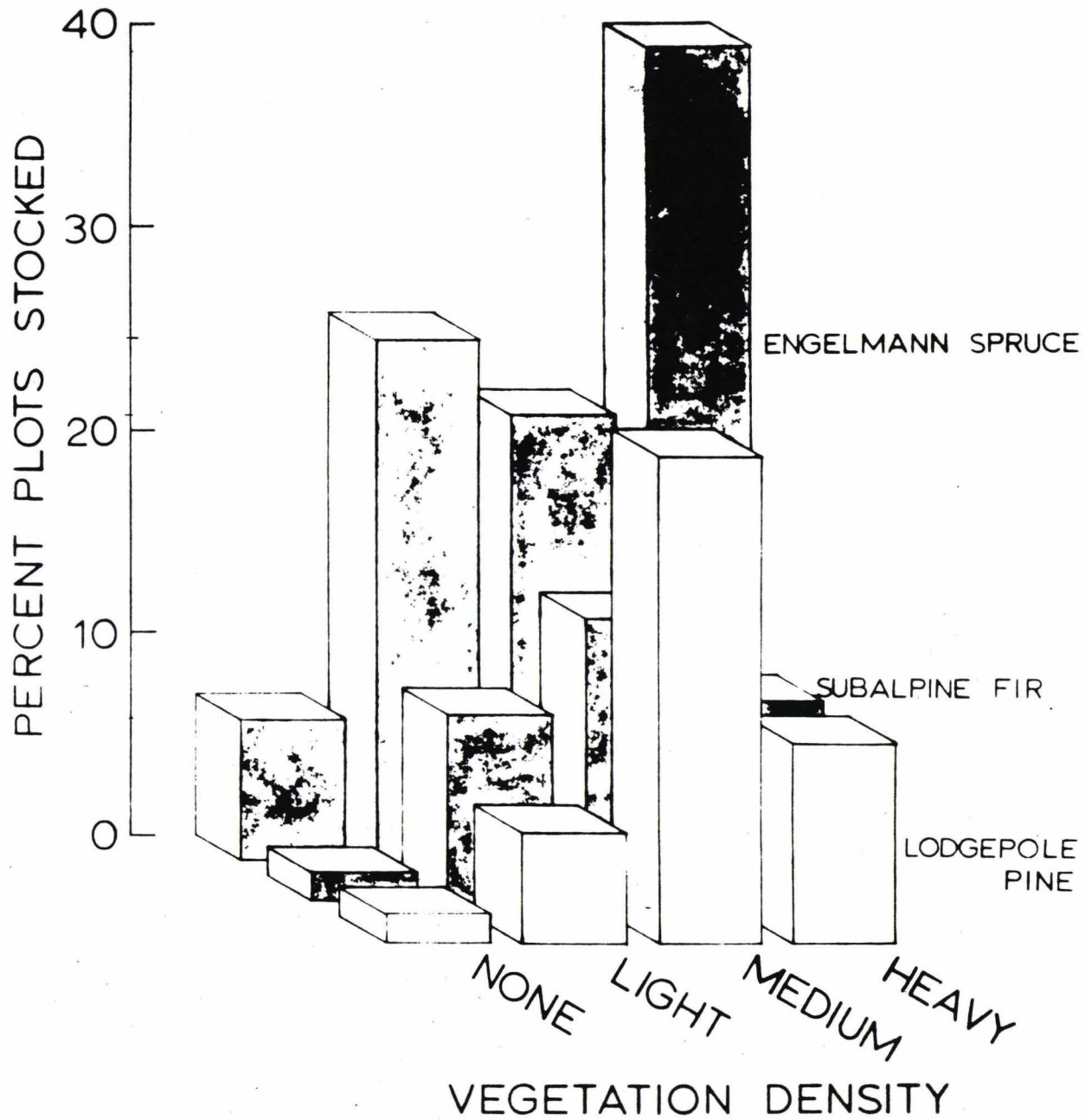
Vegetation

Vegetation such as grass, forbs, and shrubs apparently exerts a beneficial effect upon seedling survival up to a point, (figure 11). However, this relationship is one which requires further more detailed study to isolate the true facts. For example, the correlation between vegetation density and tree stocking could be mainly symptomatic of general site conditions where the site is not only better for trees, but it also favors other vegetation. It would also reflect the influence of grazing and browsing animals and it might indicate the influence of shade. Day (1964) in southwestern Alberta has shown that vegetation exerts a beneficial effect in light and medium densities but that heavy vegetation density was associated with a reduction in stocking where competition from the vegetation offset the beneficial shade and mulching effects. In our data it appears that stocking of subalpine fir and lodgepole pine has been reduced in the heavy density category, but spruce shows its highest stocking in the heavy density class.

Figure 11.--Relation of stocking and vegetation density

Figure 11.

RELATION OF STOCKING AND VEGETATION DENSITY



Since the vegetation was measured on areas mainly where seedbed has been prepared, the relative range between light and heavy classes is considerably less in 3-6 years than it will be in 10-15 years. At that time the competitive nature of the other vegetation which will have developed may be more evident and may preclude seedling development.

Soil

Texture, color, and depth of the soil did not vary enough in the data to exhibit any noticeable effect upon stocking, but a fourth factor, stoniness of the soil, did. In the field, we observed frequent examples of an affinity of seedlings to large rocks. This relationship could be related to shade since the seedlings appeared consistently on one side on the rock--usually northeast. In collecting our data, we recorded only an estimated percent stoniness of the soil. Summarizing the data, we find stocking high at low percentages of rock, low around 50 percent stoniness, and higher again at high percent stoniness. This could be interpreted to mean that on either end large scattered stones might occupy a small percentage or a large boulder on a milacre plot might constitute a large percent of the soil volume on the plot. Middle percentages are more apt to be comprised of many medium sized cobbles, or even down to pebbles, which do not provide shade. The position of the stone in relation to the soil surface is important also. Therefore, we should have recorded size, relative number and position of rocks as well as percent stoniness.

The affinity of seedlings for the rocks is so consistent that it can hardly be considered chance distribution. We believe that this constitutes a microhabitat on the seedbed. The rock surface receives about the same amount of precipitation as the surrounding soil and this moisture drains off the surface around the edges of the rock increasing the soil moisture in the vicinity of the rock. The rock also casts some shade and it may maintain a higher temperature through the night encouraging germination and faster growth resulting in more vigorous seedlings.

Disease

Damping-off fungi are known to cause serious loss in newly germinated seedlings. This is a loss, however, which can only be evaluated in detailed seedling survival studies. Daniels, at Utah State University, expressed an interesting theory which was suggested to him by Moller from the University of California, Berkeley. The organic layers near the surface furnish the best environment for damping-off fungi. Turning over the seedbed to expose subsoil would provide a mineral soil seedbed having a poorer environment for the fungus. We inspected Daniel's studies in Logan Canyon, and even though it was too early in the season (July 16) to judge seedling survival it was obvious that the subsoiling treatment showed the greatest germination. Mineral soil that had been bared but not disturbed showed much less germination.

Grazing and Browsing

Grazing and browsing animals affect the seedbed and seedling survival both directly and indirectly. While we were not able to measure the effects of animals directly, there was much evidence of an observational nature to indicate considerable animal influence.

On the southern forests, particularly, the animal damage is so severe that aspen is all but threatened with extinction. We found practically no aspen reproduction untouched and a high percentage of the subalpine fir had been seriously hedged. The prime example was one tree observed on the Dixie Forest which was about 10-feet tall and 24-feet wide. Other vegetation had been seriously reduced and the lack of cover laid the sites open to erosion. These eroding sites provided a mobile seedbed. On the other hand reduction in the grass cover provides mineral soil seedbed which is being invaded by trees. On the Aquarius Plateau, for example, seedlings are moving out into the parks. As many as 2- to 3-age classes of trees can be observed along the timber-grassland margins. Here the browsing animals are selective and browse subalpine fir, but leave the spruce untouched.

The heavy browsing and grazing has removed a lot of the cover which would provide shade for seedlings and to this extent indirectly the animals are providing a more severe site for seeding establishment.

Erosion

Erosion on the mineral soil seedbed particularly causes an undetermined amount of seedling loss. Two effects are important. Most of the soils encountered are subject to a great amount of rill and sheet erosion. Along many of the small gulleys, seedlings were found with roots completely uncovered. Only the extreme root tip of some seedlings maintained contact with the soil. Sheet movement of soil buried many seedlings. On several areas seedlings were found where only the needle tips were protruding from the soil which had been washed in by recent rains.

CLIMATE

Insolation

Insolation is known to be high at the higher elevations. Kimball (1933) shows that solar radiation measured in "grass calories/min/cm^2" range from about 1.2 at 1,000 feet elevation to approximately 1.5 to 1.6 at 10,000 to 11,000 feet. Maximum air temperatures, on the other hand rarely reach 75° F at 10,000 feet in the southern unit. Three facets of insolation are of importance to seedlings at the high elevations. They are: light intensity, heat, and quality of light.

Light Intensity

The Rocky Mountain Station is working on the effect of light intensity as it relates to seedling survival. They theorize that extremely high light intensities--14,000 feet candles at 10,000 feet--may be the factor involved in a high mortality rate during the first winter following planting. Ronco (1961) reported greater overwinter mortality in unshaded than shaded planted seedlings. Studies by the Rocky Mountain Forest and Range Experiment Station (1962) show that photosyntheses in three-year old seedlings is favored by partial shade. They suggest that seedlings grown in full light of high intensities may go into the dormant season with a shortage of food reserves. The high light intensities result in a nonreversible photo oxidation process which results in vegetative destruction.

Heat

Although maximum air temperatures rarely exceed 75° F at the high elevations, such as those found in the southern and transition unit, the influence of the higher radiation on soil surface temperatures at these elevations is not known. It is possible that lethal temperatures may be reached at the soil surface for short periods. At lower elevations in western Montana 30- to 50- percent mortality in first-year spruce seedlings resulted in gentle north slopes. Soil surface temperatures exceed 150° F several times during the summer season. Further studies will be necessary to determine maximum soil surface temperatures on the cutting areas.

Quality

The effect of light quality at the higher elevations is unknown. However, since the atmospheric layer is thinner at the high altitudes, greater amounts of ultraviolet light may be reaching seedlings on those sites. It is known that ultraviolet light can have a dwarfing effect which could influence root and top development of seedlings, thus making them more subject to drought.

Moisture

Moisture did not appear to be a critical factor in seedling survival. The relationship between increasing density of vegetation and stocking tends to show that drought is not a major cause of mortality. If moisture were a critical factor, then stocking should have been reduced by increasing density of vegetation.

Snow Pattern

Daniels[8/] has expressed the theory that moisture may be a critical factor during germination. He feels that in the spring when the seedbeds become warm enough for the seed to germinate the surface layer of soil may have dried out too much. He points out that seedlings appear in places where protection causes delayed snowmelt. Here the seedbed has sufficient moisture by the time the air temperature reaches a satisfactory level for germination. It is difficult to separate this effect from the effect of shade and detailed studies will be required to isolate these factors.

8/ Personal discussion

Summer Storms

Summer storms are prevalent in the problem areas, but they are a two-edged sword. The moisture, well distributed through the season, provided by these storms is beneficial to survival of the young seedlings while root penetration is short. Every sale area visited during the survey had ample moisture for seedlings survival. Also frequent showers were encountered. However, many of them are high intensity storms. Ellison (1954) reports storms having intensities of nearly 3-inches per hour for 5 minutes recorded at the head of Ephraim Canyon. On the Ashley Forest, we witnessed a storm of high but unknown intensity up in Mill Fork. Coming down out of the mountains in the evening, we saw debris from the plateau above coming out over the highway. Storms of this nature cause serious soil movement on unprotected seedbeds and bury some seedlings and uncover the roots on others. The extent of damage from this cause can only be determined by carefully controlled studies.

Frost

Weather records show that in southern Utah at 10,000 feet the average length of the frost-free period is 80 days. This is not only a short growing season, but there is a considerable period of time during which warm days and frosty nights may cause considerable frost action. Many places we observed the effects of frost heaving on the margins of grass clumps. The frost also has a double action in that it will heave the seedlings out of the ground or cause root damage. It will also cause soil detachment which will increase soil movement both during snowmelt and heavy rain storms. We were not able to quantify this factor in the survey, but the visual evidence convinced us that it is an important factor which must be studied.

ADVANCE REPRODUCTION

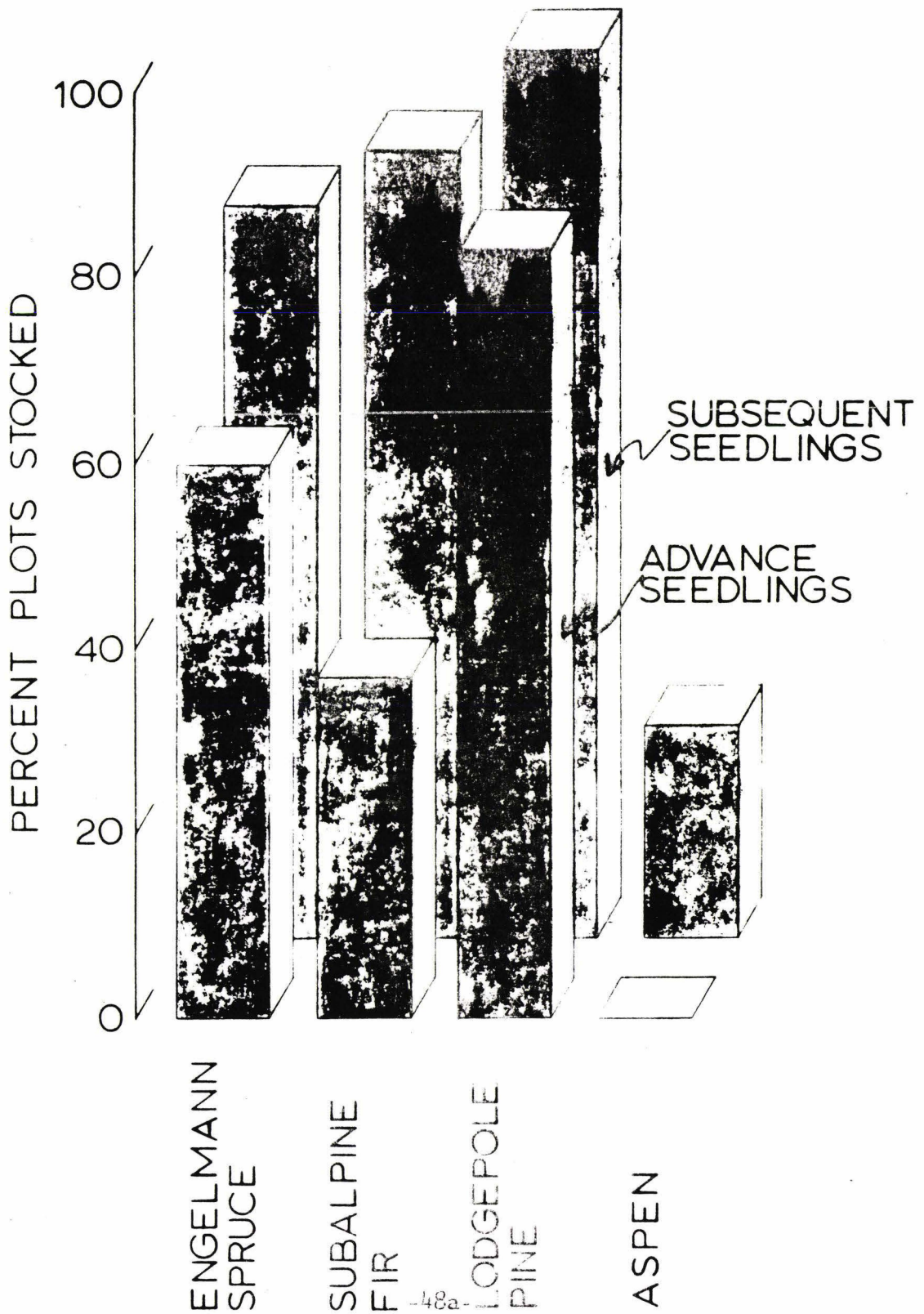
Subalpine fir dominates the advance reproduction. Of the milacre plots stocked with advance reproduction, nearly two-thirds or 63 percent were dominated by subalpine fir, 27 percent by Engelmann spruce, 4 percent by lodgepole pine, 4 percent by aspen, and only 2 percent by Douglas-fir. This distribution of species reflects the greater ability of subalpine fir to become established in conditions found under undisturbed stands. These figures are based upon values from areas which have been logged and the destruction of advance reproduction by logging, probably, was not very selective. But the ratios of species representation are considered to be reasonably representative. The distribution of species also provides a clue to their relative tolerance, with subalpine fir being the most tolerant and spruce less so. The other species are all relatively intolerant and consequently were not well represented in the advance reproduction.

Growth potential of subalpine fir advance reproduction is low. Although it comprises nearly two-thirds of the advance reproduction, only 37 percent or slightly more than one-third of it was classed as having good potential for release and growth, (figure 12). The other species, with the exception of aspen, show better potential for growth. Perhaps one reason for the better potential of spruce advance growth is that more of it becomes established in the open parts of the stand and in disturbed areas and is, therefore, more sturdy stock and not as subject to the damaging elements such as snow loads and severe competition.

Figure 12.-- Proportion of plots stocked with good potential seedlings.

Figure 12.

PROPORTION OF PLOTS STOCKED WITH GOOD POTENTIAL SEEDLINGS

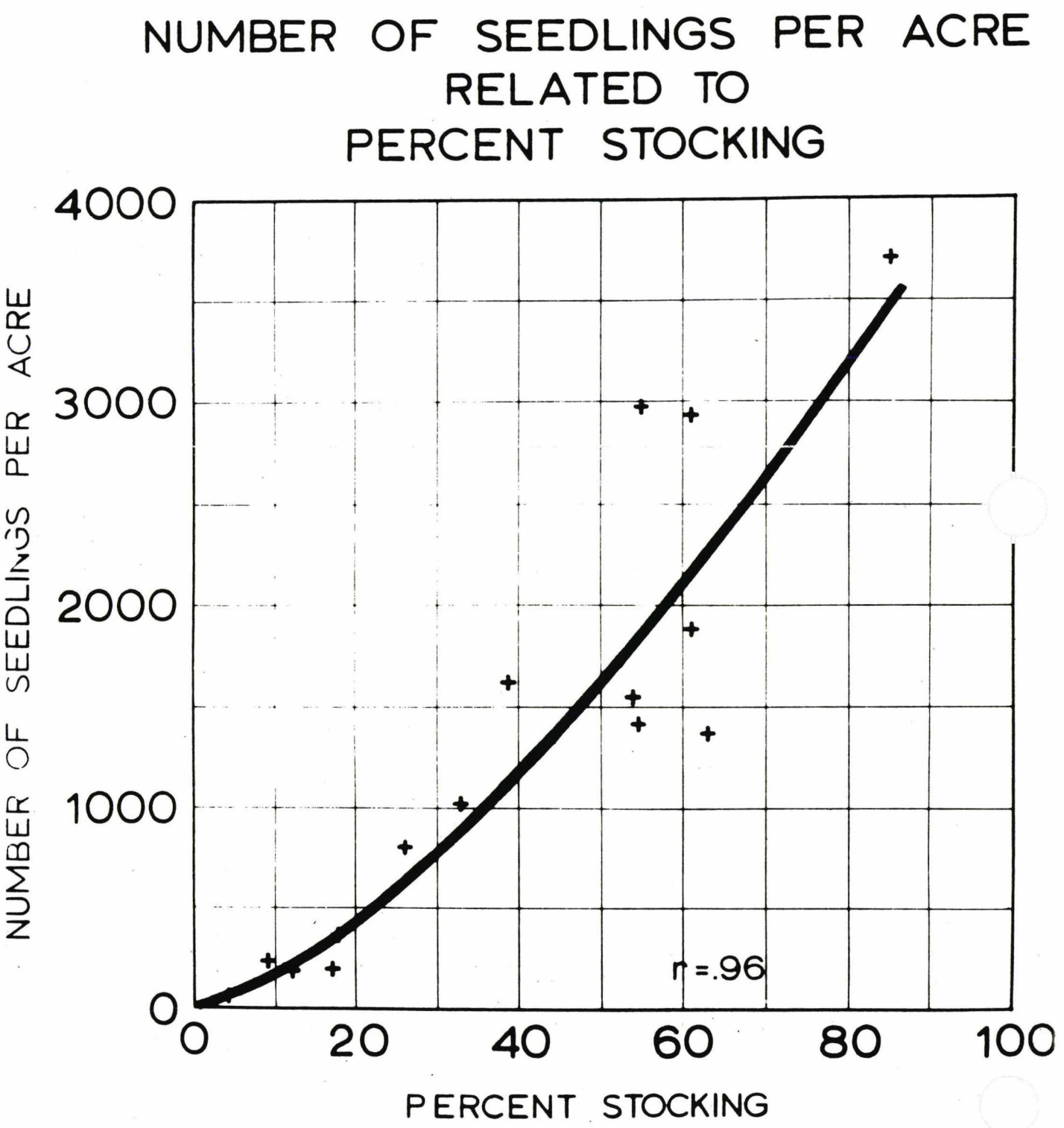


LEVEL OF STOCKING

What level of milacre stocking can we accept as sufficient to occupy an area? When we plant trees we strive to obtain from 600 to 1,000 trees per acre. On the other hand, we recognize plantations as having a degree of success if from 300 to 400 trees per acre succeed. Figure 13 shows the number of trees per acre related to the percent of milacre plots stocked. At 40 percent stocking, we find that this represents about 1,200 trees per acre or an average of 3 seedlings per stocked milacre. On this basis, two-thirds of the seedlings could be lost to mortality and still retain sufficient stocking to have 300 to 400 trees per acre. It seems reasonable, therefore, to accept 40 percent stocking of milacre plots as an acceptable minimum level of stocking. Anything below this is too poorly stocked to occupy the site.

Figure 13.--Number of seedlings per acre related to percent stocking

Figure 13.


NUMBER OF SEEDLINGS PER ACRE
RELATED TO
PERCENT STOCKING
4000
3000
2000
1000
0
NUMBER OF SEEDLINGS PER ACRE
r=.96
0
20
40
60
80
100
PERCENT STOCKING

On most of the areas visited we can expect stocking to increase with time. In Colorado Alexander (1963) has shown that increase in milacre plots stocked between 10 to 15 years after logging greatly exceeds the number stocked in the first 10 years. Therefore, we can expect that the areas involved in the survey will most likely show better stocking in the future. This applies particularly in the southern unit which not only is similar to the conditions found in Colorado, but the vegetative competition does not reinvade the seedbeds as rapidly as it does in the northern unit..

PLANTING

The planting experience in Engelmann spruce in Region 4 has been very limited. Five planting areas were visited and all but two plantings were failures. Causes of failure as nearly as could be determined were as follows:

1. Stock breaking dormancy in nursery before being lifted.
2. Poor planting techniques.
3. Stock too small or in poor vigor. (Mainly seedling stock 2-0 and 3-0.)
4. Problems of transporting stock.
5. Failure to plant seedlings in shady spots where possible.

Two areas showed some degree of success. One was on the Green River District on the Bridger Forest. In this instance 2-0 stock which they were unable to plant because of late spring in 1961 was heeled in at the Kendall Ranger Station. They lost about 25 percent of the heeled in stock, but the surviving trees were planted on a northeast facing slope in the spring of 1962. Planting was done in scalps with a planting bar and when we visited the planting in late August 1963, we found 66 percent of the trees surviving. Trees were planted at the rate of 330 per acre. This little experience indicates that the stock which had been heeled in for one year had attained a larger size and survived better than the seedling stock planted the previous spring. Plantings of lodgepole pine examined appeared to be presenting no problems.

On the Payette Forest, plantings of 2-0 and 3-0 spruce stock in scalps on the Fisher Creek burn (planted June 15, 1961) failed with 14.6 percent survival revealed by a partial count of staked rows in 1963. However, a late planting (August 26, 1962) in deep scalps (6-8 inches deep) using 2-1 transplant stock showed 59 percent survival in September 1963. It is difficult to interpret these data but it appears that the older age class coupled with the shade provided by the deep "cups" scalps and accumulation of moisture in the scalps contributed to the success.

There was not enough planting experience in spruce available to draw any conclusions. Studies designed to test the causes of failure listed above will be needed.

DISCUSSION AND RECOMMENDATIONS

Spruce sites in the Intermountain Region are critical and require great care in logging and postlogging treatments to avoid creating more severe sites. This involves maintaining as much protection for the site as possible and yet providing the microhabitat for seedling establishment and development. Evidence on the ground suggests that seed production and dispersal may be sufficient for most cuttings. However, because of the severity of the sites, large volumes of seed are necessary to provide a high probability of seed reaching suitable microsites. Two important factors must be dealt with. It appears that a paradox exists in that bared mineral soil provides the best seedbed but at the same time provides little shade for initial seedling survival. Mineral soil seedbeds are also subject to soil detachment and movement by high-intensity summer storms; therefore, soil stability must be maintained.

Established seedlings need light to grow and so they should not be directly overtopped by the overwood. Spruce seedlings release well even though suppressed for long periods of time; but it is not good management to suppress them too long. Years of suppression represent loss of growth and greatly increase the probability of fungus attack and decay before merchantable size is reached.

Windthrow in the residual trees is an important factor to consider, and great care must be exercised in the use of partial cuttings to avoid excessive loss.

METHOD OF CUTTING

Shelterwood, clear cutting in strips or blocks, and group selection are all applicable to spruce cuttings. Each present specific problems that must be met. For example, in the partial cuttings the problem of windthrow plagues the forester. However, by judiciously selecting the method to meet the situation the effect of windthrow can be minimized. Partial cuttings should be used only on moderately dry sites with deep soils. On wet soils with impeded internal drainage we are inviting trouble with partial cuttings. Avoid locating partial cuttings on or near ridge tops or saddles where winds are funneled or concentrated. Take caution also not to locate the boundaries of clearcuts on or very close to ridges or saddles and other physiographic features which cause winds to funnel or concentrate.

Partial cuttings also present difficulties connected with seedbed preparation. Either broadcast burning or scarifying the soil around the base of spruce trees can damage the roots of seed trees. This damage may stimulate seed production but it also leaves the residual trees much less windfirm than they were. In fact, on some areas where a good hot burn is achieved, residual spruce trees may topple before the smoke settles.

Clear cuttings have the advantage of being open to seedbed preparation. The work can be done without danger of damaging the residual and it is cheaper to do than in the partial cuttings.

The size of openings in clear cuts should be restricted so that no part of the seedbed is greater than:

One tree height from timber edge - Southern Unit

Two tree heights from timber edge - Transition Unit

Three tree heights from timber edge - Northern Unit

The timber edge should be a well-stocked stand comprised of thrifty, mature, full crowned, vigorous trees. Stands that have been decimated heavily by spruce beetle or other insect attack or reduced by heavy cutting are usually not a good seed source and it may be necessary to plan later planting.

ADVANCE VERSUS SUBSEQUENT PRODUCTION

Nearly every mature spruce-fir stand has an understory of advance reproduction. These understories may range from very sparse stocking by occasional trees to an extremely overstocked condition. These trees may be young--in their teens or less--or they may have reached 80 to 100 years of age--half rotation age--and still be the same size. They may span the range of vigor, and often suffer breakage or malformation from snow loads. The advance growth, particularly subalpine fir, may be spindly and highly subject to snow damage because of long suppression. Some of the subalpine fir may have been infected with heart rots through snowbreaks. Browsing may cause serious malformation and slow growth. In no case should the advance reproduction be taken for granted. Its condition should be carefully ascertained by close systematic inspection. Such an inspection in our survey revealed that only about one-third of the subalpine fir and about two-thirds of the spruce was classed as good potential stocking. If the good potential trees stock 40 percent or more of milacre plots and the trees are not more than 30 years old by the time they reach 4.5 feet in height, the stand could be considered stocked. However, the stocking should not be considered in good shape until the poor potential trees have been removed and the good potential trees are released and given adequate growing space. Intervening nonstocked areas should then be considered for subsequent regeneration.

SEEDBED PREPARATION

Seedbed preparation may be accomplished either by broadcast burning or thorough scarification of the ground surface with a brush blade equipped tractor.

It appears that the best seedbed preparation can be accomplished with broadcast burn. However, there are certain things that must be accomplished by the burn. It must consume most but not necessarily all of the duff or organic layer on the ground. It must burn hot enough to destroy some or all of the competing vegetation, but it must not burn so hot that a large accumulation of loose ash results on the mineral soil surface or cause color changes in the mineral soil and fractures in the rock. It must leave large quantities of charred wood and material of large enough size to provide considerable shade and protection on the ground. Timing of the burn will be exceedingly important. The key to the time to burn would be when the moisture content of the duff is low enough that it will smolder and carry a creeping fire, consuming duff. If only the surface is dry, a hot fire may run over the surface and blacken it but not consume duff. Experimentation will be necessary to determine when the duff layer is dry enough to do the job.

Mechanical scarification with care can also accomplish a satisfactory seedbed. A complete cleanup job is not necessary nor is it desirable. There is a double advantage in not cleaning up too well. First, the residual material--tops, etc.--provides shade on the seedbed, and second, material on the seedbed and untouched intervening strips or patches protect the site against excessive soil movement. When a thorough cleanup is made and the material windrowed and burned, the hot fire sterilizes the soil and covers it with a deep, fluffy layer of loose ash, which is a very poor seedbed. It takes an undetermined number of years before these spots become receptive seedbeds again. Therefore, the concentrations should be confined to the least possible area for burning. If possible, the duff layer should be removed along the contour, preferably in strips, with untouched strips intervening. Some of the debris should then be pushed back on the scarified strips for protection and the dozer walked over it at right angles to the strips, breaking it down. It may not be necessary to burn the slash if the trampled slash meets the Regional fuel standards.

RESEARCH NEEDS

Limited research in the spruce-subalpine fir type has left many unanswered management questions. Increased demands upon the type requires prompt solution to problems in natural regeneration, harvest, site determination, growth, and yield. Answers to the question how to regenerate spruce stands successfully are of utmost importance now and will require research in depth for ultimate solution.

NATURAL REGENERATION

Consideration of research needs in natural regeneration breaks down into three general categories, namely: seed, seedbed, and environment, including climate.

Seed

Production.--The research objective in production studies is to learn the amount, quality, and frequency of seed produced by spruce seed trees of different age classes, crown class, vigor, and other conditions. Specific studies will be required to:

1. Determine criteria for selecting productive seed trees.

2. Record annual seed crops to determine frequency and periodicity of good seed production.

3. Study the effect of release, fertilization, and other stimulation measures upon seed production.

4. Follow the course of cone development from ovulate bud to mature cone, determine amount and cause of mortality, and develop effective seed forecasting methods.

Dispersal.--The purpose of dispersal studies is to determine the factors affecting natural seed distribution and learn the effectiveness of different cutting methods in achieving good dispersal. Solutions to the dispersal problems entails study of:

1. Different patterns of cutting.

2. Distance of seed travel from individual trees or timber edge.

3. Influence of physiographic and climatic features upon dispersal including source of seed dispersing winds (i.e. thermal vs prevailing, etc.).

Germination.--The object of studies in this category is to identify and determine the effect of both internal and external factors upon germination. Some of the solutions to germination problems may be gained by studies of:

1. Seed quality including germinative capacity, energy, and viability of spruce seed in the problem areas.

2. Soil texture, moisture, temperature, and light in relation to germination involving both field and greenhouse studies.

3. Chemical and physical germination promoters and inhibitors and the effect of chemical leachates upon germination.

4. Hardwood versus coniferous litter.

Seedbed

To a large extent the crux of the spruce regeneration problem lies in the microhabitat of the seedbed. The effect of shade, depth of organic matter, physical elements of soil, and other vegetation (important both as protection to and competition with seedings), are largely symptomatic of more basic factors influencing seedling survival. Studies in depth are necessary to isolate the causal factors. This involves field, greenhouse, and laboratory studies.

The objective of seedbed studies is to identify, quantify, and evaluate factors causing seedling mortality, and to determine the most effective seedbed type and condition to minimize seedling mortality. Following are the kinds of studies needed to provide answers to seedbed prolems:

1. Test seedling survival under controlled conditions on several types of seedbed.

2. Study the influence of soil factors such as depth, texture, stoniness, stability, and moisture on seedling survival.

3. Determine the specific relationship of the depth of organic matter (L. F. and H. layer) to seedling survival.

4. Work out the role of animals in seedling mortality.

5. Relate the success or failure of natural regeneration to physiographic sites.

Environment

Climate influences many facets of the life history of a spruce forest. It may determine seed crop years, affect germination, and cause seedling mortality. The effect of climate may be direct or indirect. In any event, climate must be more clearly understood in relation to spruce sites than it is now. Practically no climatic data applicable to the spruce sites is available. Most of the climatic records are taken in valley bottoms, cities, airports, and like places which are separated by miles of distance and feet of elevation from the study sites. Detailed climatic studies in relation to seedling survival are necessary for the purpose of determining limiting climatic factors.

The following studies are needed:

1. Study seedling survival in relation to insolation, both light and heat, drought, precipitation, evaporation, and frost.

2. Study of critical climatic factors by problem areas and by physiographic sites.

3. Determine means of measuring climatic factors cheaply, in automatically recorded form.

ECOLOGY

Our ecological knowledge of the spruce-subalpine fir type is limited. Present knowledge suggests some of the more obvious relationships of the type to fire, succession, associated tree species and other vegetation. There are a number of studies that should be made as a basis for more intelligent management of the type. They are:

1. Classify spruce stands. This would involve determining site types, physiographic sites and stand distribution by ordination methods.

2. Determine the extent and significance of hybridization between Engelmann and Colorado blue spruce.

CUTTING TRIALS

The purpose of cutting trials is to devise harvest cutting methods which will harvest the timber and provide for prompt regeneration of the desirable species on all stand conditions. There is still considerable controversy between clear cutting and partial cutting or basically evenaged versus unevenaged management concepts for Engelmann spruce. Therefore, the trials should encompass partial cutting as well as clear-cutting methods. The studies outlined up to this point provide basic information for designing cutting tests. The following studies would be considered minimum tests to be installed:

1. Clear cut -- 1-to 5-chain wide strips.
2. Block clear cuts.
3. Shelterwood cuttings.
4. Group selection.

SEEDBED PREPARATION METHODS

Studies have shown certain seedbed requirements for successful germination and seedling survival. In conjunction with method of cutting trials, studies are needed to test several methods of preparing ground to provide the basic seedbed requirements. Available methods to be tested are:

1. Prescribed broadcast burn.
2. Mechanical scarification with dozer and brush blade.
3. Chemical reduction of competition.
4. Combinations of the above.

MANAGEMENT OF ADVANCE REPRODUCTION

Information is needed to enable the forest manager to decide when the advance reproduction is worth saving and developing and when it should be destroyed to favor subsequent reproduction. How long can advance reproduction be suppressed and still respond satisfactorily to release? How does growth on subsequent and advance reproduction compare? What treatments and stocking levels favor reasonable growth and yields from advance reproduction? To arrive at solutions to these questions, studies such as the following are needed:

1. Determine the ability of spruce to respond to release under various degrees of suppression at various ages.

2. Compare growth and yield of subsequent versus advance reproduction.

3. Determine levels of stocking, release requirement, and other practices needed to get adequate growth and yield from advance reproduction.

4. Determine the incidence of disease in the advance reproduction.

PLANTING TESTS

Even under the best of conditions the results of natural regeneration in spruce is highly variable. Failures will occur. Therefore, in our spruce management we must be prepared to backstop failures in natural regeneration with planting. However, before we can anticipate successful planting the following kinds of studies should be made:

1. Determine the optimum size and age class of planting stock.

2. Test season and methods of planting.

3. Study nursery practice to learn how to develop best stock for the variety of field conditions encountered.

GROWTH AND YIELD

Suitable tables of stocking, growth, yield, and site are nonexistent for the spruce-fir type. One very urgent need in the type from the Dixie Forest to the Canadian border is to develop suitable site, growth, and yield data.

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